Dieter Brunnschweiler *

East Lansing, Mich.

THE PERIGLACIAL REALM IN NORTH AMERICA DURING THE WISCONSIN GLACIATION

Abstract

The existence of frost-debris and tundra zones adjacent to the ice sheet in North America during the Wisconsin advance has been doubted because of the negative results of most pollen records. This is surprising since, theoretically, climatic conditions must have been as conductive to permafrost formation as in more oceanic Europe where the wide distribution of periglacial phenomena is well known.

On the basis of geomorphologic and pedologic analysis, however, the evidence for periglacial morphogenesis is convincing. On the Atlantic Coastal Plain, the Piedmont, and in the Appalachians cryoturbation and solifluction is much more widespread than formerly believed (frost-debris mantle, soil involutions, ice wedge casts, polygonal structures in hardpans, boulder streams, loess and inland dunes, thaw lakes). In the Midwest and the Great Plains frost-disturbed soils occur all along and even within the Wisconsin terminal moraines and are particularly frequent in the Driftless Area of Wisconsin. Unique and well-retained forms of patterned ground (silt mounds and tongues surrounded by stone circles and stripes, respectively) were found in the Pacific Northwest. They occupy several hundred square miles, mostly on Columbia Plateau basalt and defy any explanation other than intensive former permafrost action.

The distribution of periglacial and related features (loess, snow line, biota) was used to reconstruct the morpho-climatic zonation of southern North America in the last cold phase of the Pleistocene.

THE PROBLEM

Pleistocene morphogenesis on the North American continent has been the topic of scientific investigations for over a hundred years. Particular attention was directed toward those portions of the continent which show direct evidence of glaciations and there is wide-spread though by no means complete agreement on the major phases of Pleistocene glaciations.

Quite in contrast the status of knowledge about the evolution of landforms in non-glaciated North America is so meager that we have to base our reasoning on speculations rather than on the synthesis of the observed evidence. The periglacial realm with which I am mostly concerned in this context has received only very sporadic attention. The pioneering studies of Bryan (1946) and his pupils, as well as those of Taber (1929), Smith (1949a), and Washburn (1956) contributed much toward the

* Department of Geography, Michigan State University, East Lansing, Michigan (U.S.A.).

understanding of the „periglacial cycle of erosion" (Peltier 1950), but a regional interpretation of Pleistocene periglacial morphogenesis is still missing.

Major contributions to the knowledge of the North America „periglacial" came from the quarters of the biologists, notably Deevey (1949) and Sears (1932). However, upon inspection of pertinent literature it seems that the periglacial biotope of North America ist still a highly controversial topic and, as stated by Potzger (1951) „the old, old tundra problem" has never been solved. At the same time as new evidence is brought forward that Wisconsin ice overrode living forests in Ohio (Goldthwaite & Burns 1958) recent pollen spectra and fossil fauna from widely scattered localities seem to indicate tundra conditions in the same area (Martin 1958; Wayne 1955/56; Livingstone 1958).

The tundra, however, is not only a vegetational association but a morphoclimatic unit par excellence. If a treeless tundra did fringe the North American ice sheet morphogenetic analysis must be able to shed light on its extent, its character and its relation to the ice pulsations. It is the purpose of this paper to present the available evidence for a periglacial zone in North America during the Wisconsin stage of glaciation.

„FOSSIL" FROZEN GROUND PHENOMENA IN NORTH AMERICA

As early as 1881 Kerr reported from coastal plain, the piedmont and the Blue Ridge of North Carolina the observation of block streams [1], thick accumulations of angular rock debris „in earths of great depth" at the bases of valley slopes, and asymmetrical valleys. Referring to the block streams he said „,...freezing and thawing would give rise to... the same movements as in a true glacier... In other words they were earth glaciers, and these deposits may be nominated frost drift — as distinguished from proper glacial drift" (Kerr 1881). This is, to my knowledge, the earliest explanatory reference to a phenomenon of solifluction in North America. A great variety of inactive periglacial phenomena has since been described from widely scattered areas of eastern United States, especially from the Appalachians (Smith 1945; Peltier 1949; Denny 1951), the White Mountains (Antevs 1932; Goldthwaite 1940) and the mid-Atlantic coastal plain (Denny 1936; Wolfe 1953).

[1] It is interesting to note that Professor Kerr investigated these block-streams because they contained placer gold „which had settled due to movement by frost". The clairvoyance of this observer is all the more astounding if one considers the distance of more than 200 miles to the then still vaguely known southern limit of glaciation and the fact that he had never seen active solifluction himself.

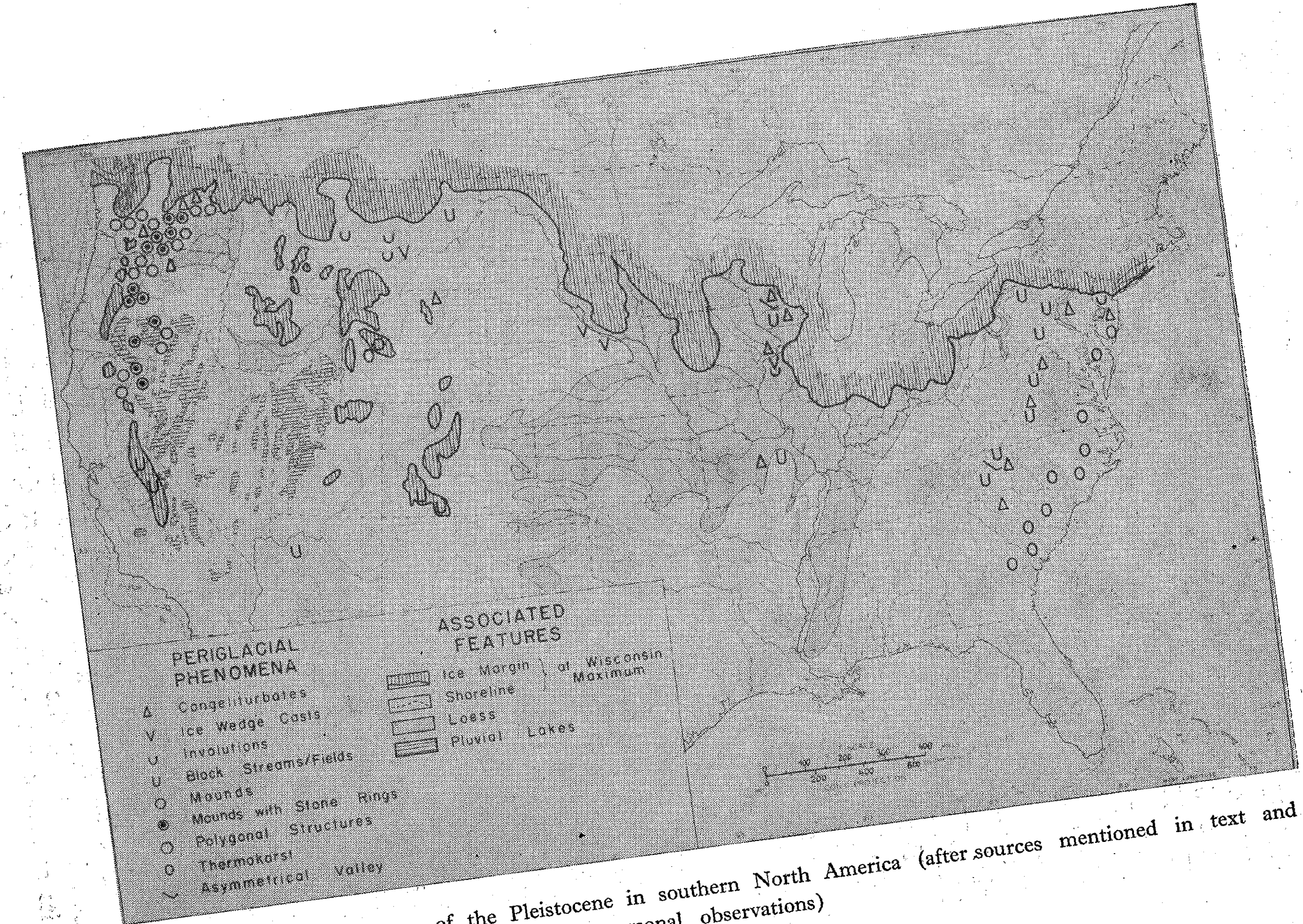

Fig. 1. Periglacial phenomena of the Pleistocene in southern North America (after sources mentioned in text and personal observations)

The most frequently encountered forms are: block streams and boulder fields, talus congeliturbates and non-glacial gravels, sorted stone rings and stripes, involutions, ice-wedge casts, and aeolian deposits (fig. 1). Nikiforoff (1955) has interpreted polygonal structures in hardpan soils of southern Maryland as results of ground-frost action and refers to similar phenomena in hardpans of Tennessee and Kentucky uplands. The New Jersey and Delmarva peninsulas contain a large number of circular depressions with interior drainage which have been interpreted by Wolfe (1953) as periglacial frost-thaw basins. From here it is only one step to the Carolina Bays which have been shown to be similar to the thermokarst lakes of northern Alaska (Black & Barnsdale 1949). The origin of the Bays might well be reanalyzed with proper regard to the obviously widespread and intensive periglacial activity in southeastern North America.

The Midwest and the Great Plains have fewer known periglacial structures than one would expect, but those which have been described are well developed. The most conspicuous permafrost phenomena are found in the Driftless area of Wisconsin where conditions for their development were undoubtedly ideal. Boulder streams and fields, non-glacial gravel trains and terraces, corrosional and often asymmetrical valleys all give evidence of intensive and widespread periglacial activity (Smith 1949b). The southernmost solifluctional features in central United States are block streams and fields in the St. François mountains in eastern Missouri (Peltier 1950) and on the Ozark plateau. They lie 3—400 meters higher than the nearest lowland sites (involutions) in southern Illinois. In central Montana classical examples of involutions and frost wedge casts were described by Schafer (1949), often developed in loess and reaching depths of 250 cm. The sand and loess accumulation in the Mississippi-Missouri basins still presents a considerable interpretational problem. Their aeolian nature is no longer doubted, but it still makes for a difficult mental exercise to derive the vast sand and silt deposits from the outwash trains of the plains' rivers. Recent grain size analyses in eastern loess areas of the United States show that alluvial loess can be successfully differentiated from periglacial loess (Millette & Higbee 1958) and further work in the Midwest might very well prove that the postulated frost-debris tundra, lying upwinds from the major loess areas, contributed substantial amounts of fines to the loess mantle. The fact that disturbed soils have only been found in Farmdale and Peoria (i. e. early and middle Wisconsin) loess should indicate that (1) loess accumulation pre-dated or accompanied the early Wisconsin stages of the ice advance, (2) the tjaele was already in existence when the ice reached its southernmost position, and (3) permafrost activity was less pronounced in this part of North America in the late stages of Wisconsin time. This might explain to some extent the scarcity of frozen-ground phenomena in Wisconsin till or outwash which has led such serious students of the American Pleistocene as Flint (1955) and Goldthwaite (1959) to question the existence of a periglacial zone, at least as far as South Dakota [2] and Ohio are concerned.

Progressing westwards to the Rocky Mountains, the intermontane plateaus, and the Cascades the expectation for finding a variety of periglacial land-forms was not only fulfilled, but greatly surpassed. At many sites the character of the structures is so obvious that it seems almost unbelievable that they have escaped attention altogether or, where known, are often inadequately or incorrectly explained. Since most of the field work was carried on in the intermontane plateaus of Washington and Oregon this area will be presented in more detail.

THE PERIGLACIAL PHENOMENA OF THE COLUMBIA PLATEAU*

DISTRIBUTION

Several hundred square miles of the basalt plateaus of the Pacific Northwest are characterized by surface forms which, in most cases, defy any other explanation than that of former intensive cryoturbation and solifluction. The accompanying map (fig. 2) shows the presently known distribution of „fossil" ground-frost and related phenomena in northwestern United States.

It will be noted that they extend from the Wisconsin terminal moraine in the north over most of the intermontane plateaus as far south as northern California. The altitude of the sites increases from near sea level in the Puget Sound area to above 1500 meters in northeastern California. The lower limit of presently active ground-frost, known from very few places only, seems to lie at least 1600 meters above that of the Pleistocene. Extensive loess accumulations, with a thickness of above 30 meters in many loca-

[2] Flint (*ibid.*) expresses the following opinion: „The negative result (in the search for periglacial phenomena) supports the view that the shrinkage of the successive Wisconsin glaciers was not accompanied by climates as rigorous as those which prevailed in some others peripheral sectors of the Wisconsin drift sheets."

* Field work in western United States was carried on in summer 1958 with the aid of an All University Research Grant of Michigan State University. I wish to thank Dr. M. R. Kaatz of Central Washington College (Ellensburg) for his cooperation in the field, the procurement of photos, and new data on the problem of the Columbia Mounds.

tions, mantle most of southeastern Washington except where washed away by the „Spokane Floods" (Bretz 1956).

The striking patterned ground in this area consists of the following structures:

(1) Sorted and unsorted congeliturbates, mostly, but not exclusively, of basalt. They form well-defined circles, polygons, and stripes, or rubble and boulder fields.

(2) Silt mounds, isolated or in groups, perfectly circular to ovoid or elongated into tongues. Circular depressions are typical in non-mounded silt (loess) territory.

(3) Combinations of (1) and (2).

Of particular interest are mounds concentrically girdled by stone rings (fig. 3, pls. 1—5).

The underlying rock material is Tertiary basalt, in some cases Pleistocene conglomerate and till. The soil of the mounds is silt loam, residual

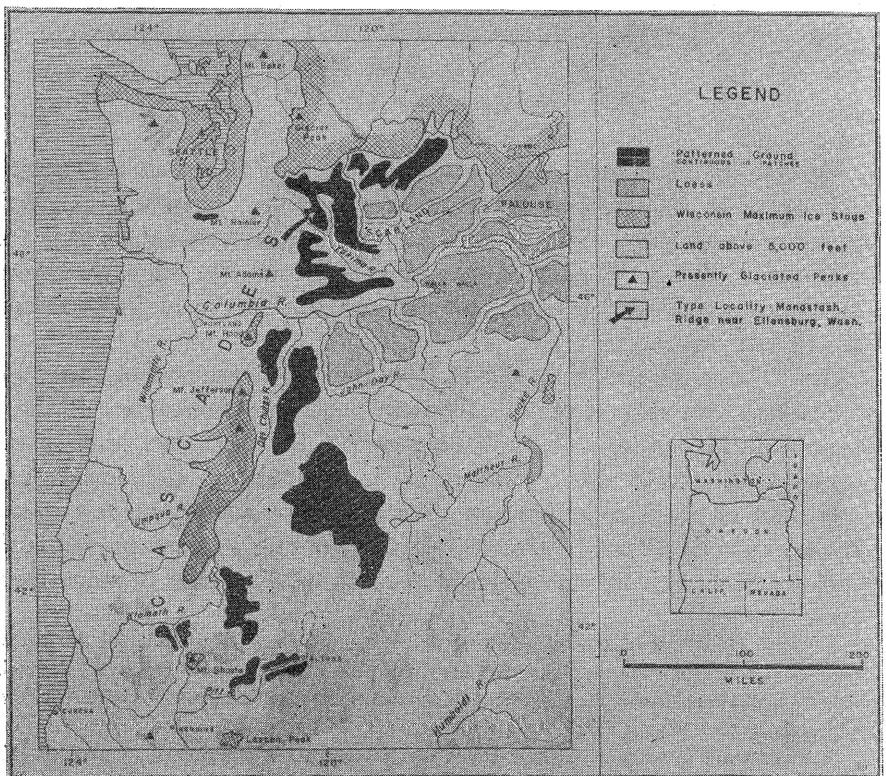

Fig. 2. General distribution of frost-patterned ground, particularly of the „Columbia Mound" type, in northwestern United States.

on loess which here is rarely thicker than 180 cm. A typical mound is 90—120 cm high, flat-topped, and 10—15 meters in diameter, often covered rather densely with grasses, herbs, and shrubs [3].

The inter-mound surface consists of strongly weathered basalt which also underlies the mounds disconformably; it is practically barren and makes the typical „scabland" of the local jargon.

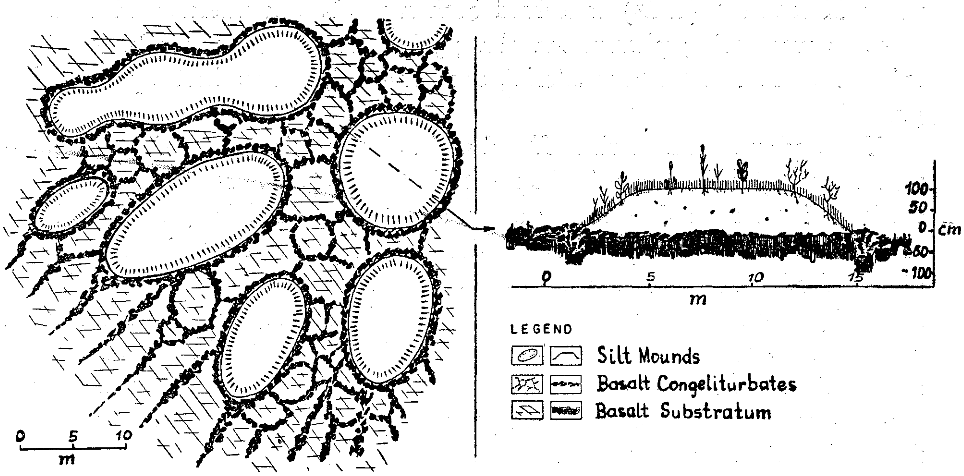

Fig. 3. Schematic ground plan of a group of stone-ringed „Columbia" mounds and cross section of a typical individual

A cross section through the mounds and the substratum reveals that the girdling stone rings consist of large subangular basalt blocks in the upper portion, many of them standing on edge. Below the 50 cm level the fragments are much smaller and fines fill the interstices. In no case did sorted structures exist underneath the mounds. The occurrence of basalt fragments up to 3 cm in diameter in the silt of the mounds has an important bearing on the postulated aeolian origin of the silt mantle.

The density of the mounds varies greatly: more than five per acre are not uncommon while wide dispersions alternate with concentrations where the mounds actually coalesce. Very typical are groups of mounds on the broad divides between the deeply incised canyons. Here the mounds are drawn out along the fall lines and form beaded strings, often with lateral stone stripes which continue into the steep canyon walls.

[3] In areas of high mound density it is quite common practice with farmers to planate the mounds in order to fill in the barren inter-mound space so the land can be used for wheat cultivation.

THE ORIGIN OF MOUNDS AND STONE CIRCLES

At least three theories concerning the origin of the patterned ground in the Columbia Plateau have appeared in print, the majority of them dealing mostly with the mounds. Waters and Flagler (1929) explained them „as wholly the result of surface erosion" and the stone nets as „erosion furrows" of a „minutely adjusted drainage system". Larrison (1942) postulated that the mounds are the result of borroughing gophers (Geomys), while Knetchel (1952) conceived both mounds and intermound structures as weathering phenomena along joints of the columnar basalt, in spite of the fact that other material, as mentioned, also underlies patterned ground.

The explanation herewith offered maintains that intensive frost action under a periglacial climate is the most important single factor in the formation of the mounds and the stone assortations. All indications point toward the existence of permafrost with an active layer depth in the order of magnitude of 150—200 cm. Wherever the loess mantle exceeds a thickness of 200 cm solifluction phenomena are indistinct or absent. In the thicker loess mantle in southeastern Washington no evidence of frost action has been found. Vigorous cryoturbation and solifluction was only possible where subsurface drainage was practically prevented by the frozen basalt lying near the surface.

To this writer the major problem to be solved in explaining the origin of the Columbia frost structures is the role the loess mantle played in the process of mound formation. There is little doubt that the silt mantle was once contiguous (accordant summit levels of mounds) and that most of it existed already in the early phases of the Wisconsin advance. This is the same situation which we have already observed in the Midwest. As soon as freezing penetrated to the bedrock congelifraction and congeliturbation processes were initiated. With the evolution of polygonal and circular structures in the basalt the hanging silt layer divided itself into circular units which eventually developed into separate mounds. The occurrence of the basalt fragments in the mounds, however, indicates that the latter were actively involved in the cryoturbational process and cannot be explained just as residual erosional or entirely aeolian features [4]. Kaatz (1959) has postulated two phases of ground patterning, the formation of stone nets postdating that of the mounds. However, the perfect concentricity of mound rims and stone circles, the occurrence

[4] Péwé (1954) has described a group of similar mounds near Fairbanks (Alaska). He attributes their formation to the „melting of a network of ice masses in the ground" with subsequent slumping of material into the circular depressions. The case is, however, not strictly comparable because of the absence of stone circles.

of basalt fragments in the silt, and the theoretical consideration that all material above the permafrost level must have been involved in cryoturbation, once the active layer reached down to the basalt substratum, seems to indicate a simultaneous development of mounds and stone structures. Also, it is quite possible that much of the so-called loess is actually the fine fraction of the congeliturbate, but the analysis of the fines is not yet available to substantiate this theory.

The dating of the permafrost period in relation to the advance and retreat of the Wisconsin ice sheet is a most intriguing problem. The large diameter of the stone circles, the depth of the frost-shattered rubble, and the partial removal of the loess mantle all speak for a long duration of periglacial morphogenesis. Of utmost importance with respect to dating the periglacial period is the study of the relationship between the patterned ground and te channels (*coulées*) created by the repeated floods (Bretz *et al.* 1956) on the Columbia Plateau in the early stages of deglaciation. Even though the best-developed of the stone-girdled mounds are found on the uplands between the coulées frost-patterned ground is by no means absent on their floors. On the plateau remnants between the coulées, which have been affected by early floods only, numerous distinct ground-frost phenomena have been observed. It is, therefore, reasonable to assume, that the Plateau area was still under the regime of a climate favoring ground-frost at a time when the ice had already retreated from its terminal moraine in northern Washington [5].

THE PERIGLACIAL ZONE IN NORTH AMERICA DURING WISCONSIN TIME

A SYNTHESIS

On the basis of the distribution and the character of fossil groundfrost phenomena on one hand and with the help of the presently available paleobiologic record on the other, an attempt has been made in reconstructing the periglacial realm as it may have existed during the maximum stage of the Wisconsin glaciation. Although the area south of the periglacial zone was not the object of this investigation it has been included in the paleoclimatic map by taking into account all pertinent information on the evolution of landforms and the biotic record of southern North America in the late Pleistocene. The following conclusions seem justified at the present time:

[5] The recent study on the channeled scabland of Washington by Bretz, Smith, and Neff (1956) does not include the importance of periglacial morphogenesis. Professor Smith, however, states in correspondence that the question has not been studied enough to arrive at the conclusion stated above.

(1) Periglacial phenomena have a much more widespread distribution in North America than formerly believed. Geomorphic evidence warrants one locating the equatorial limit of frozen ground several hundred miles south of the ice margin in the western high plateaus, in the higher Appalachians and possibly on the Atlantic seaboard. In the Midwest a periglacial zone is well recognizable but is of more limited latitudinal extent. However, if one considers the great loess triangle as genetically related to periglacial morphogenesis — and permafrost phenomena in the loess justify one to do so — the Great Plains have to be included within the periglacial realm.

(2) The plant record is still too spotty to be conclusive as to the southward migration of the tundra. While some pollen profiles indicate tundra conditions at considerable distances from the ice, others give no evidence

Fig. 4. Climate and vegetation of southern North America at Wisconsin Maximum
This map is an attempt to reconstruct the climatic conditions in southern North America during the Wisconsin stage of the Pleistocene. It is based upon the presently available geomorphologic and paleobiologic evidence. Note in particular the frost-debris tundra the boundaries of which were drawn according to the distribution of known sites of periglacial phenomena

of absence of trees, at least as far as postglacial time is concerned. The dated spruce forests of Ohio, evidently still alive when the Wisconsin ice first reached them, are difficult to explain in a periglacial environment. That a periglacial climate became effective shortly thereafter, however, can be interpreted from strong solifluctional evidence in the same area.

(3) The occurrence of typical tundra animals such as the musk ox (*Ovibos*) and the reindeer (*Rangifer*) in fossil sites close to or even beyond the southern limit of the periglacial zone, and that of the woolly mammoth (*Mammuthus primigenius*) and the bison as far south as Florida and Mexico, respectively, must indicate a marked latitudinal displacement of North American biotopes. The Great Plains, in which the Pleistocene biotic record is still too scanty and poorly dated, may be differentiated into a northern loess tundra, a central loess steppe, and a southern forest steppe, the last grading into a boreal forest with both coniferous and deciduous species, the former dominating in its northern portions, the latter farther south.

(4) The paleoclimatic map of North America in Wisconsin time should be understood as a first and very approximative integration of the morphologic and biologic evidence presently available (fig. 4). If, at the same time, one takes into account the changed pattern of atmospheric circulation it should be possible to outline the climatic zonation of North America during the maximum stages of Pleistocene glaciations with a reasonable degree of accuracy. In order to facilitate the reading of the map, the symbols of the Koeppen clasification of climates have been added. The following zones (formation classes) have been differentiated, progressing from north to south:

1. Glaciated Zones (EF)
2. „Alpine" and „Polar" Tundra, with continuous permafrost (ET)
3. „Alpine" and „Polar" Tundra, with discontinuous permafrost (ET)
4. Loess Tundra, treeless (ET)
5. Loess Steppe, with galerie forests (BSk)
6. Forest Steppe (BSk-Dfb)
7. Boreal Forest, conifers dominating (Dfb, Cfb)
8. Mixed Forest, deciduous trees dominating (Dfb, Cfb)
9. Evergreen Hardwood Forest (Mediterrenean vegetation) (Csb)
10. Subtropical Steppe (BSk, BSh)

(5) A great deal of work, both on the morphologic and the biologic front, has to be accomplished before we can understand the evolution of the Pleistocene landscape in North America which is, with little alterations, the landscape in which we live today.

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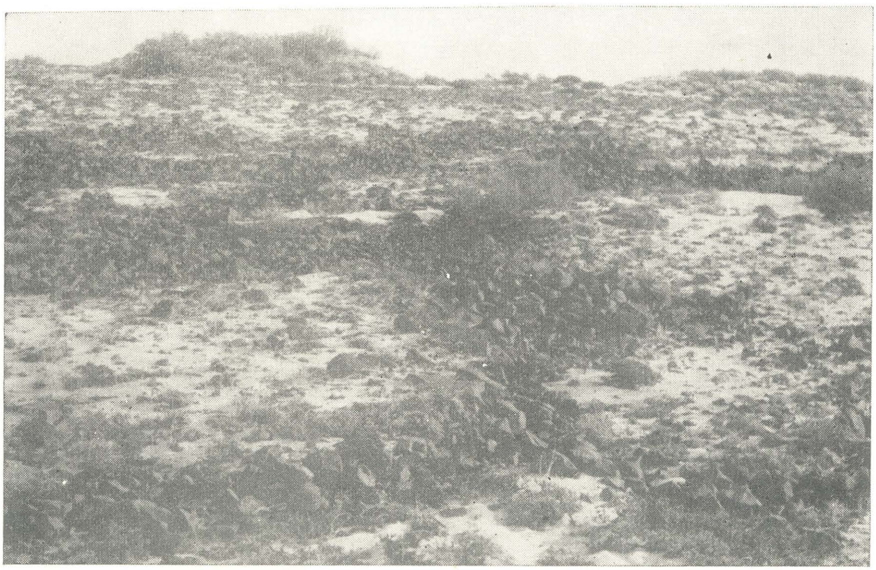
Pl. 1. Stone-encircled mound on Manastash Ridge, Kittitas County, Washington. Freshly fallen snow accentuates contrast between mound and strone ring. Note polygonal assortations in flat intermound area. Mt. Rainier faintly visible in right background



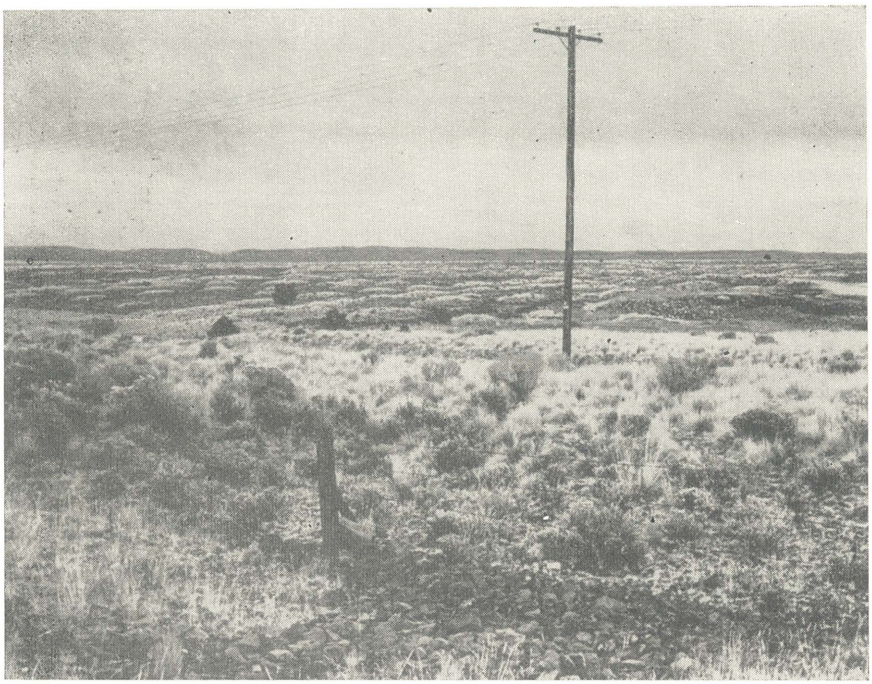
Pl. 2. Basalt congeliturbate with polygonal and circular structure. Two mounds are silhouetted in background (Thorp Prairie, Kittitas County, Washington)

Pl. 3. Dissected mound showing homogeneous texture of silt loam and the inclusion of some sharp-edged basalt fragments. Note saturated condition of soil indicated by miniature mudflow to the left of spade

Photo U.S. Dept. of Agriculture

Pl. 4. Aerial view of Yakima River canyon and Manastash Ridge between Ellensburg and Yakima, Kittitas County, Washington

A multitude of mounds is visible on the highest portions of Manastash Ridge to the lower left, mostly aligned along fall lines like beaded pearl strings. Also note the basalt stone strips appearing as dark lines on the canyon walls.



Pl. 5. A swarm of mounds on the plateau above the Deschutes River, Wasco County, Oregon. Assorted basalt rubble in foreground